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Title: Systematics of the UC ν tau Experiment

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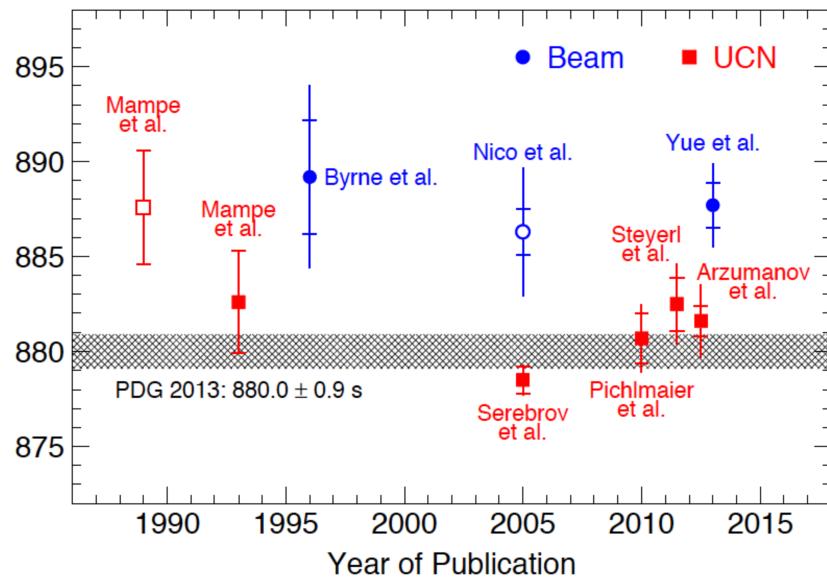
Systematics of the UCN τ Experiment

R.W. Pattie Jr for the UCN τ Collaboration

Los Alamos National Lab

October 11, 2014

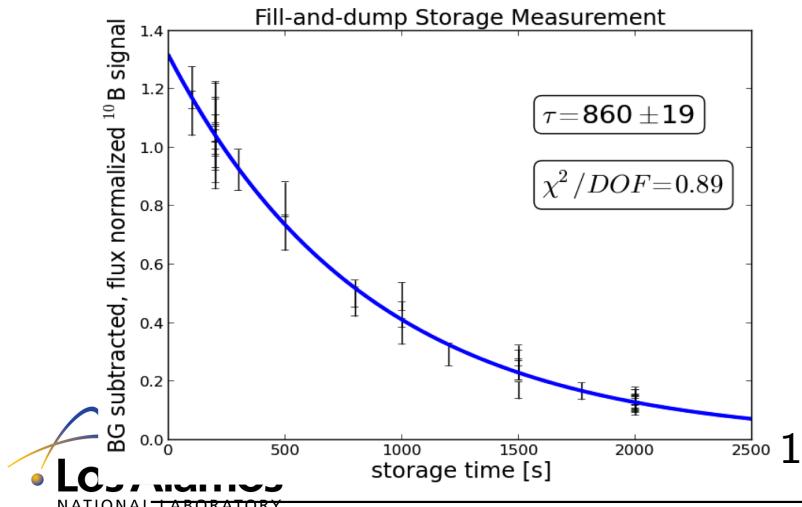
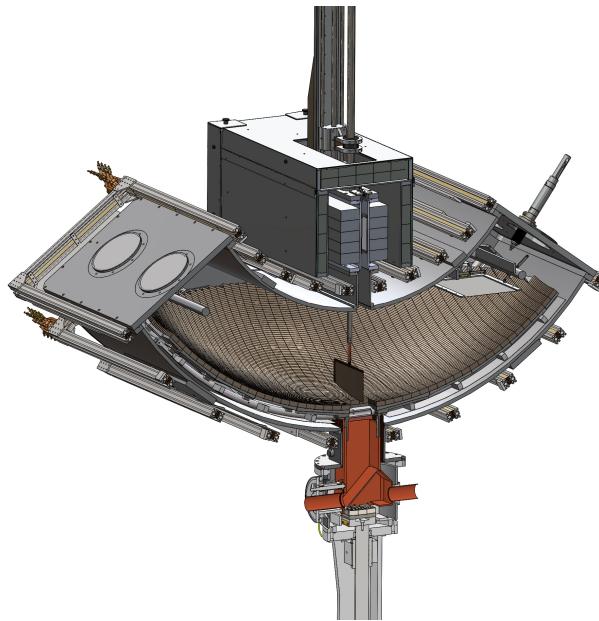
Overview I



- $\sim 4\sigma$ discrepancy between CN beam and UCN trap τ_n measurements

- 1 $\tau = \frac{4908.7 \pm 1.9 s}{|V_{ud}|^2(1+3\lambda^2)}$
- 2 Combined with angular correlation parameter to determine $|V_{ud}|$
- 3 Directly impacts ${}^4\text{He}$ abundance in the early universe

Overview II



- ① Located at the LANSCE spallation UCN source

- Capable of loading the trap with $\sim 50k$ UCN per fill
- Allows for ~ 1 s measurement in a weekend of running

- ② Magneto-Gravitational Trap

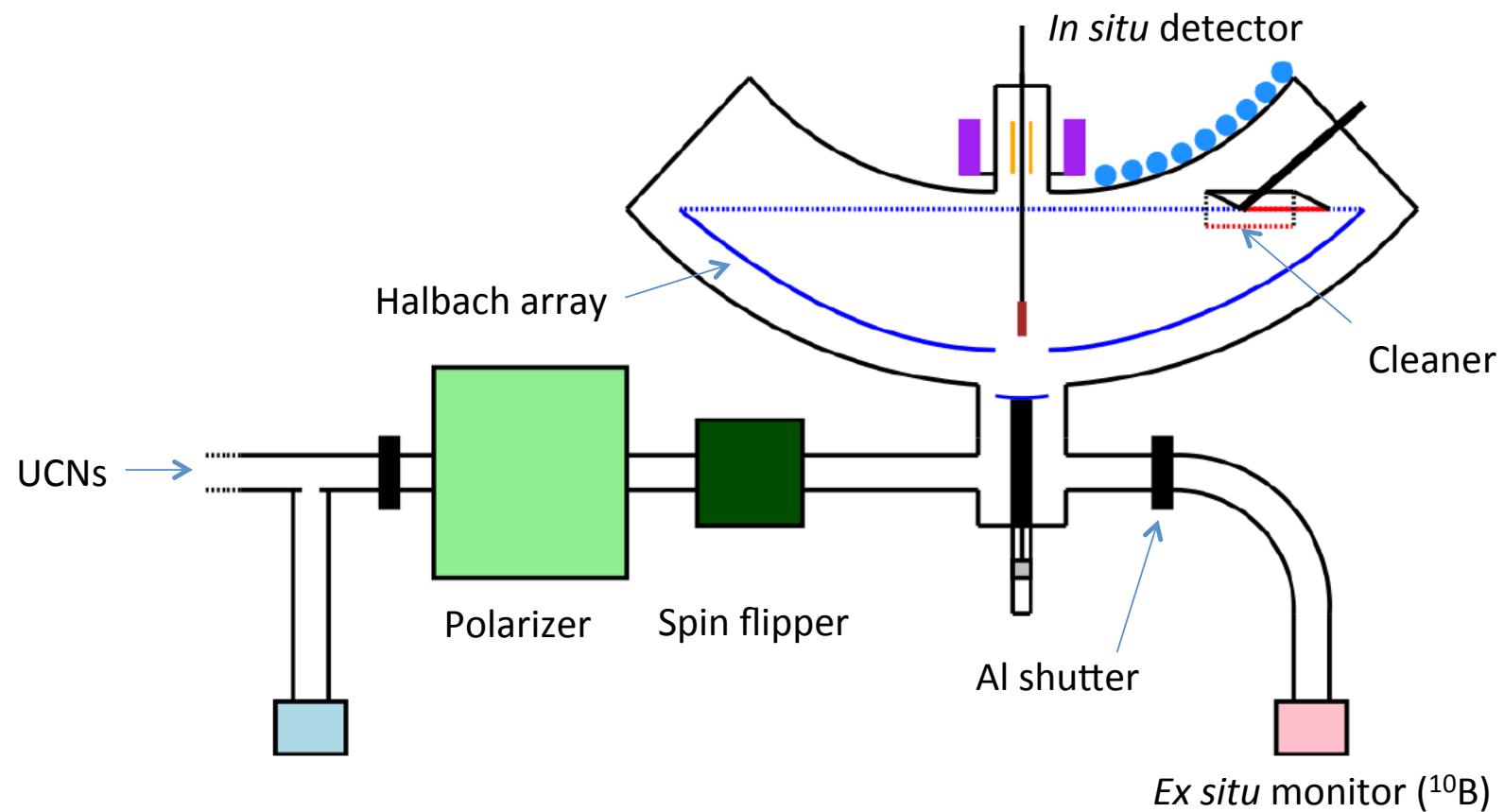
- Permanent Halbach Array confines UCN from below
- Gravity holds UCN in from top
- Minimizes Material interactions

- ③ Multiple Counting Methods

- Traditional Fill and Dump
- Count the activation of Vanadium foil

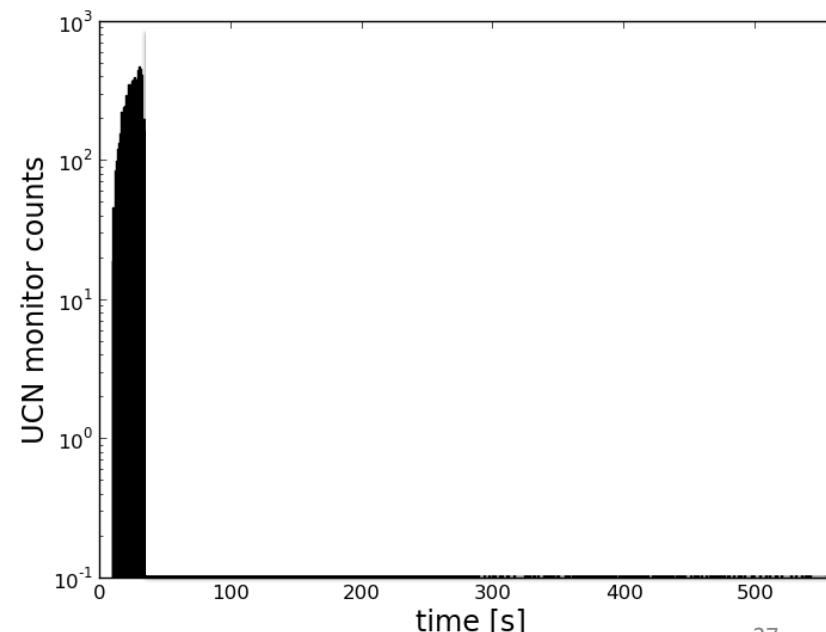
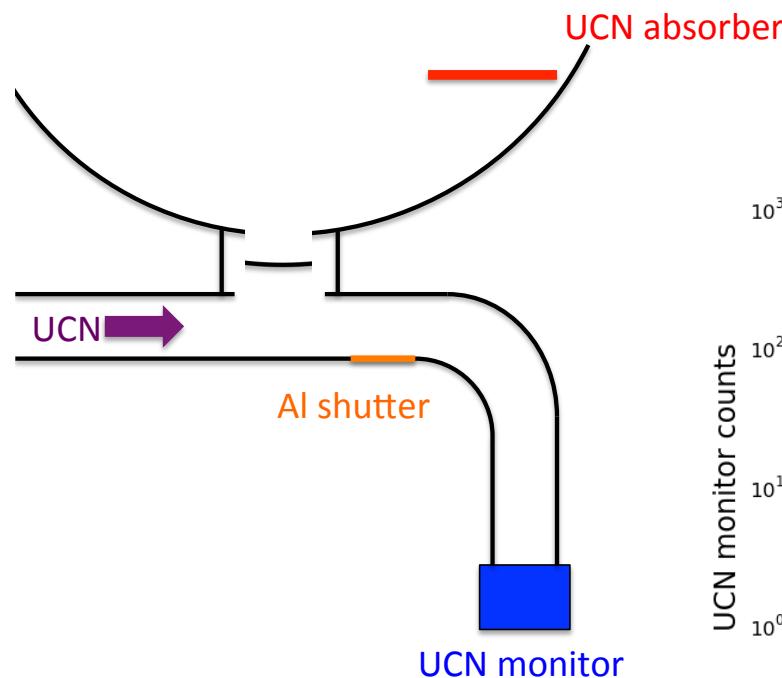


Overview III



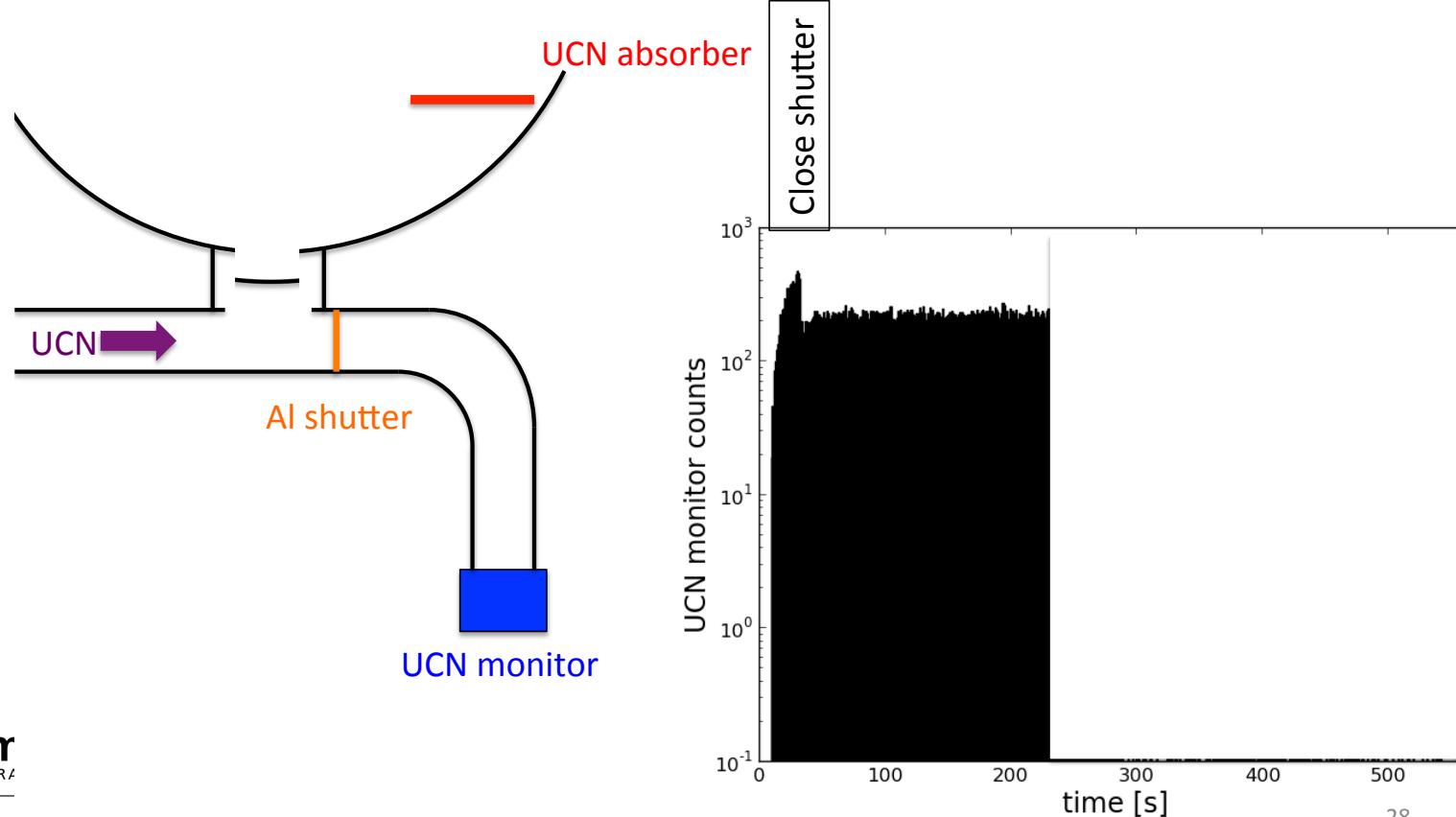
Measurement Cycle

Fill-and-Empty Measurement



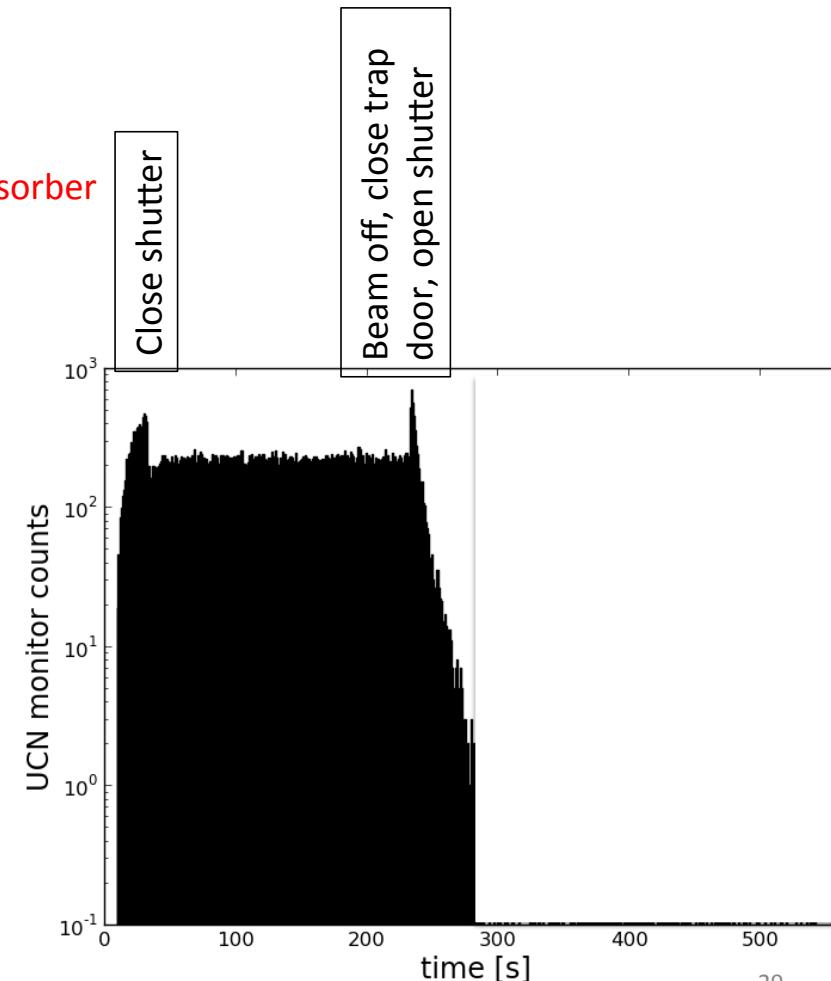
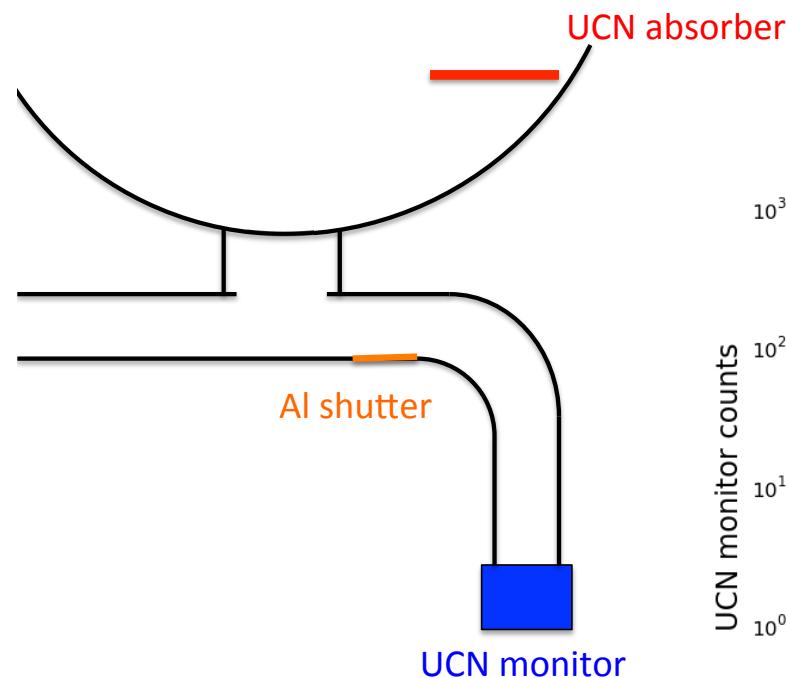
Measurement Cycle

Fill-and-Empty Measurement



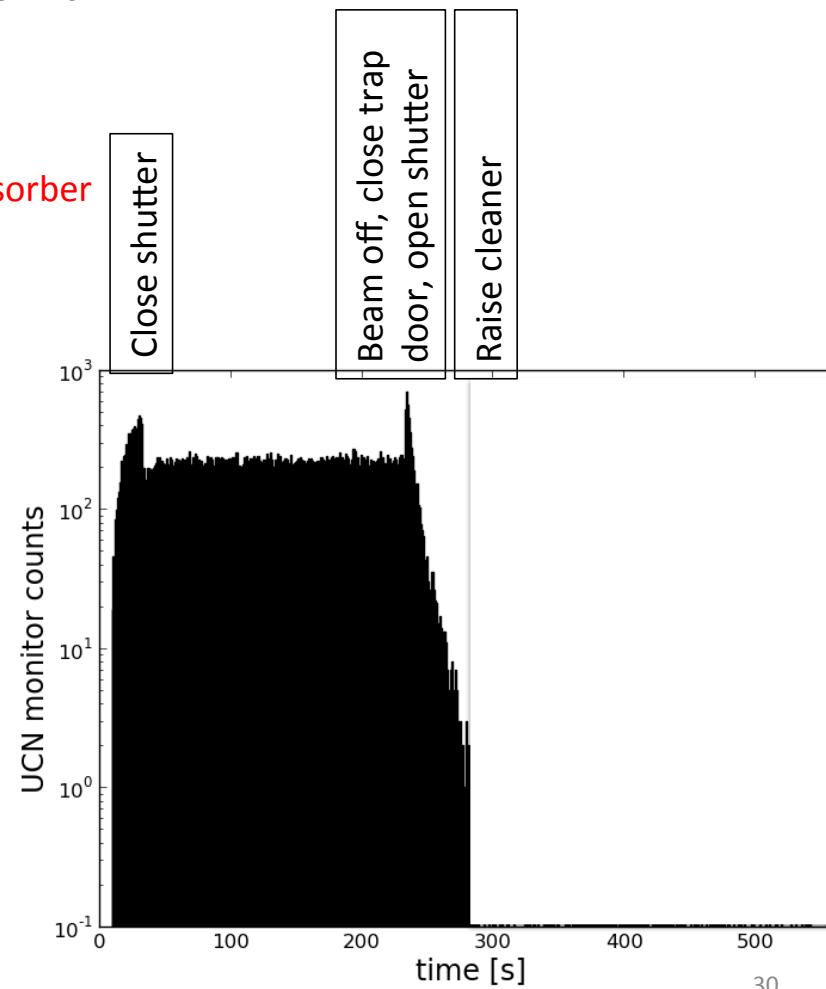
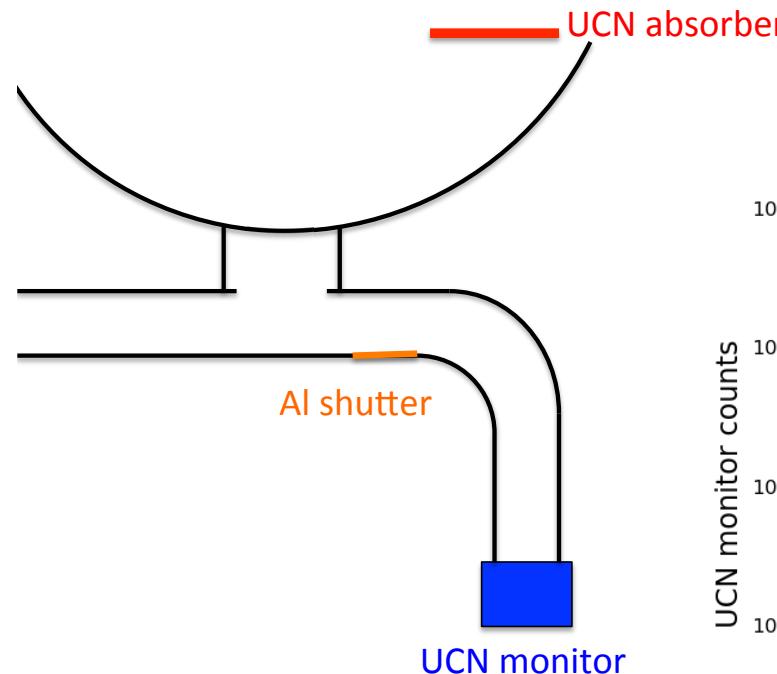
Measurement Cycle

Fill-and-Empty Measurement



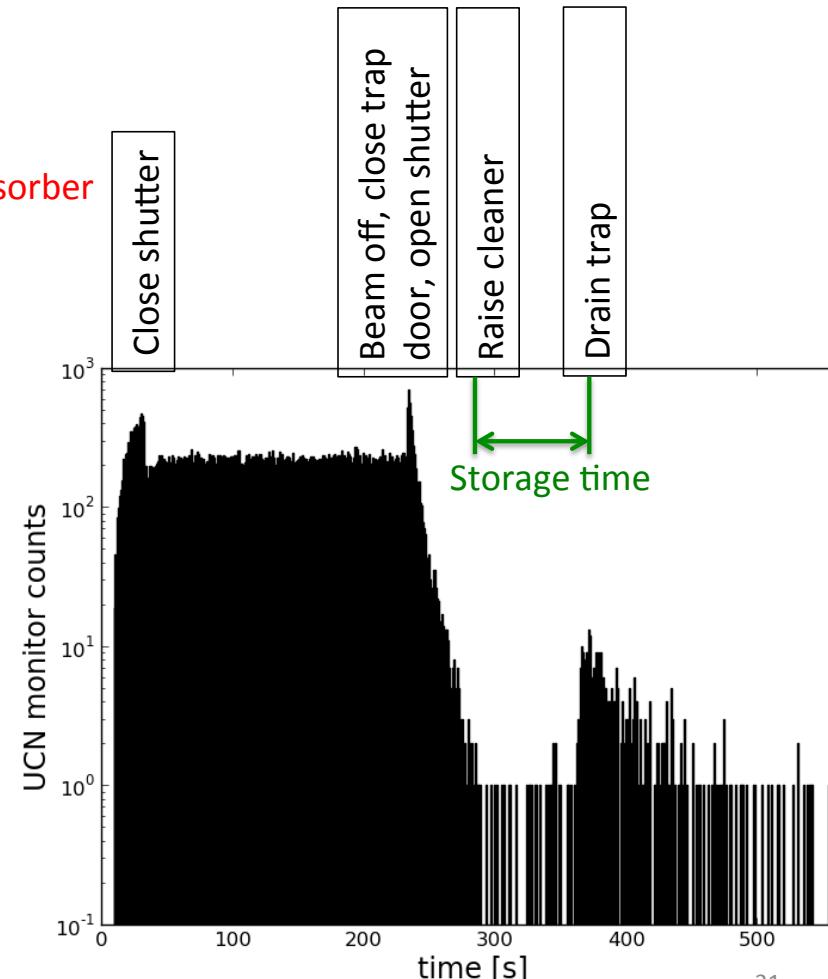
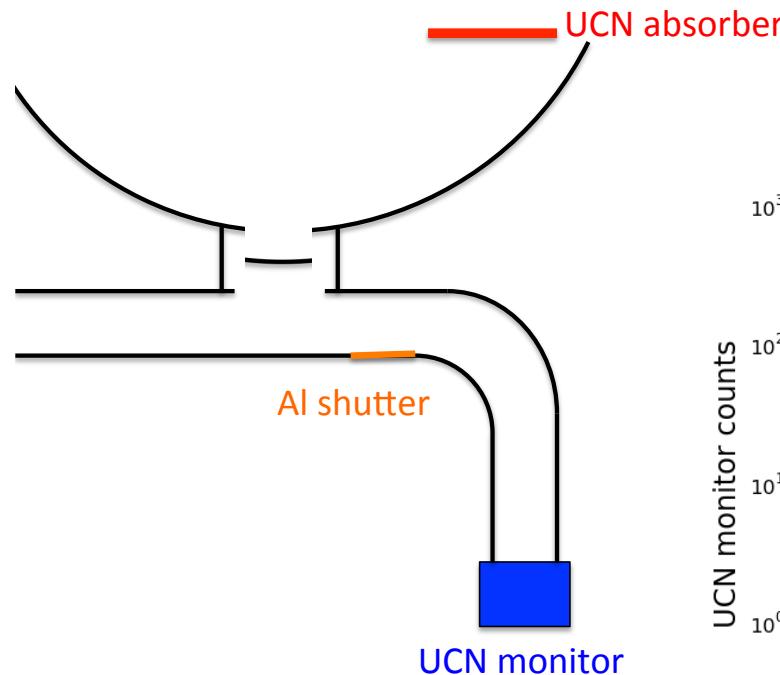
Measurement Cycle

Fill-and-Empty Measurement



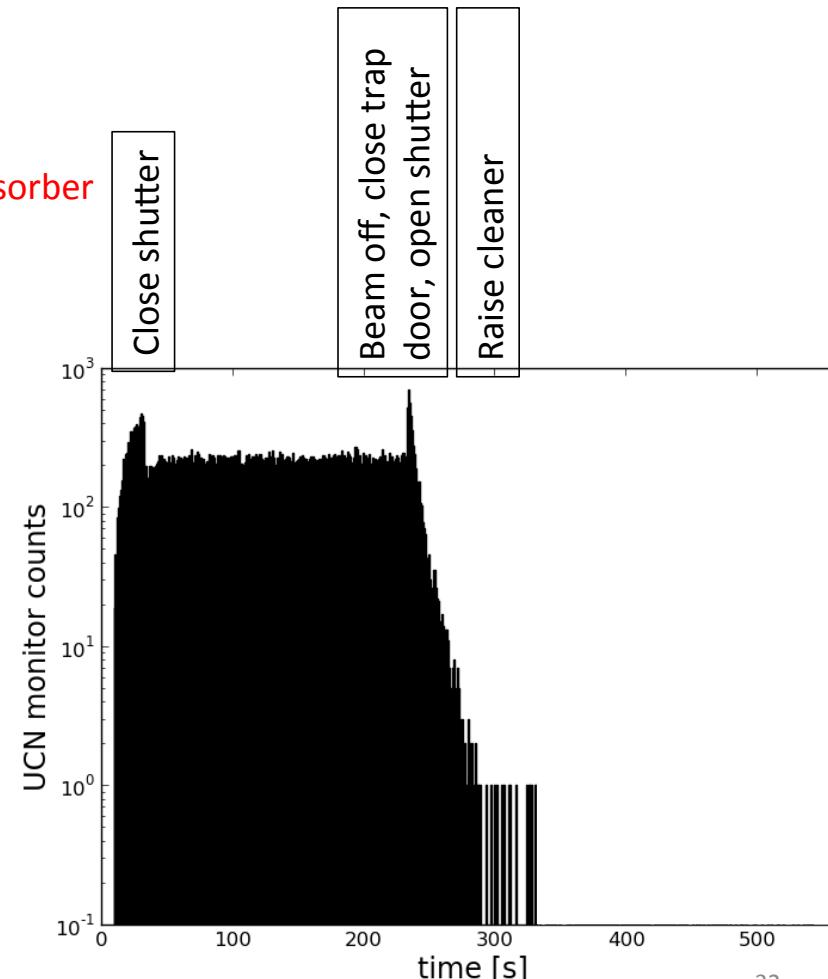
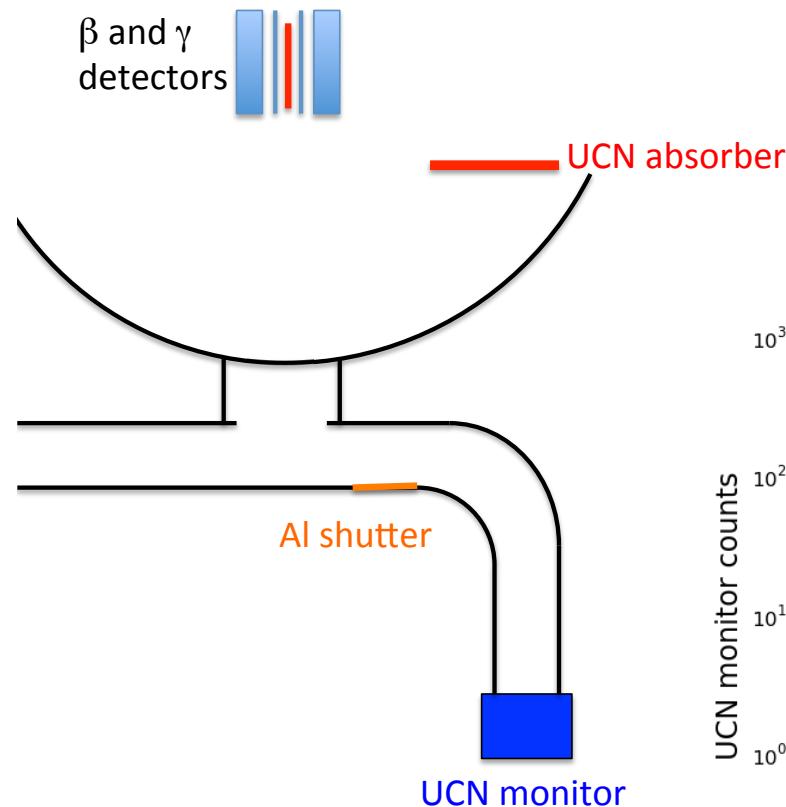
Measurement Cycle

Fill-and-Empty Measurement



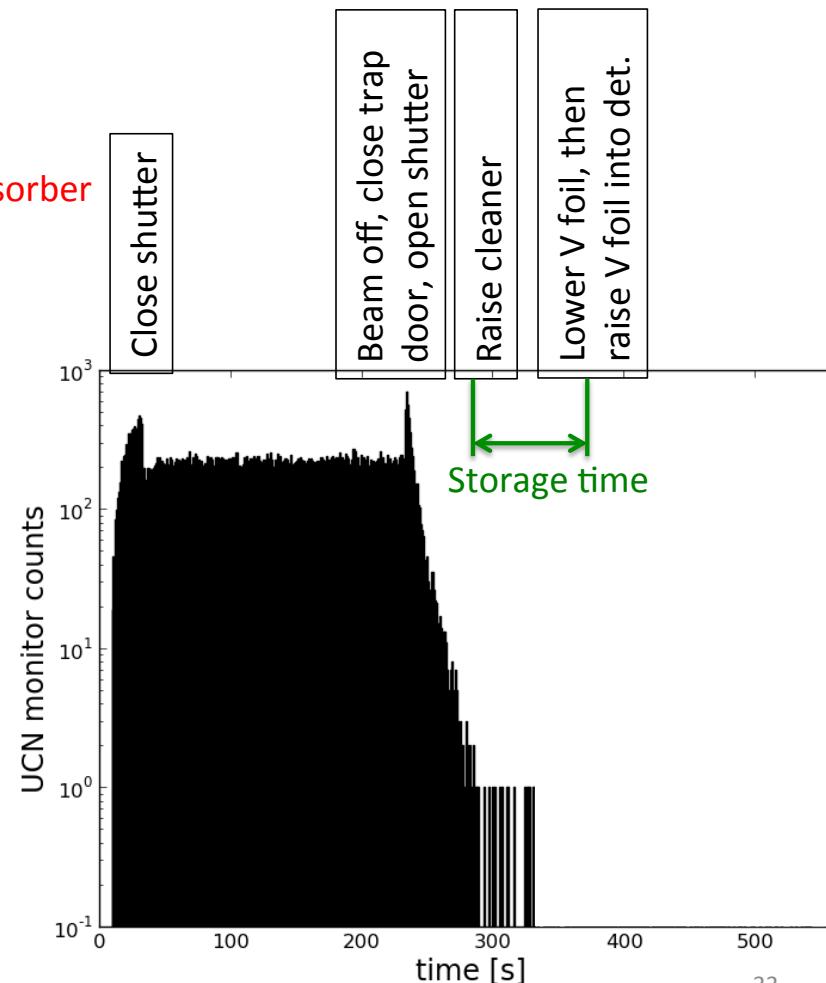
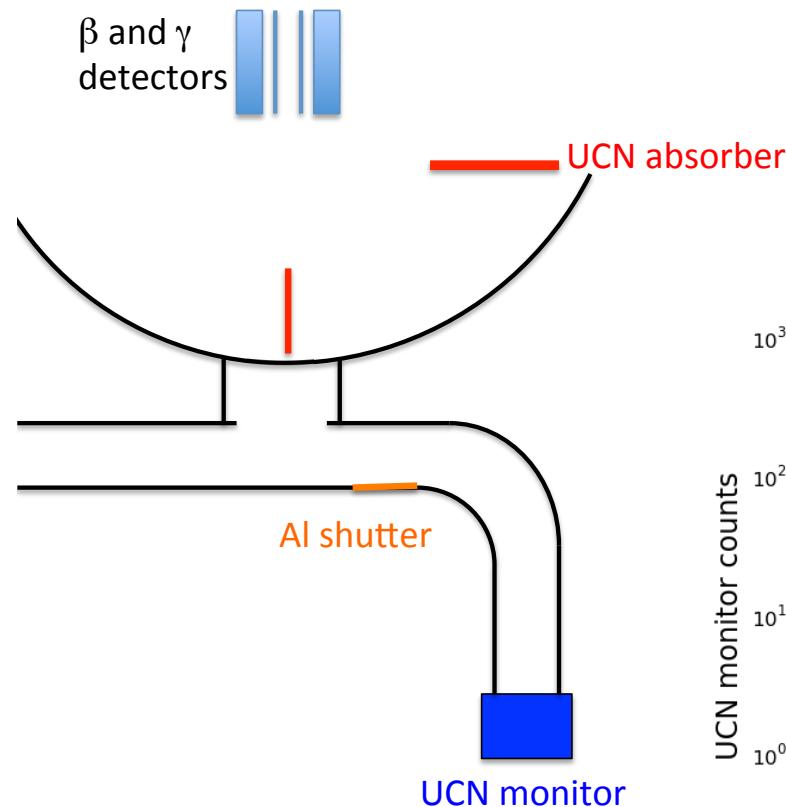
Measurement Cycle

Fill-and-Detect Measurement



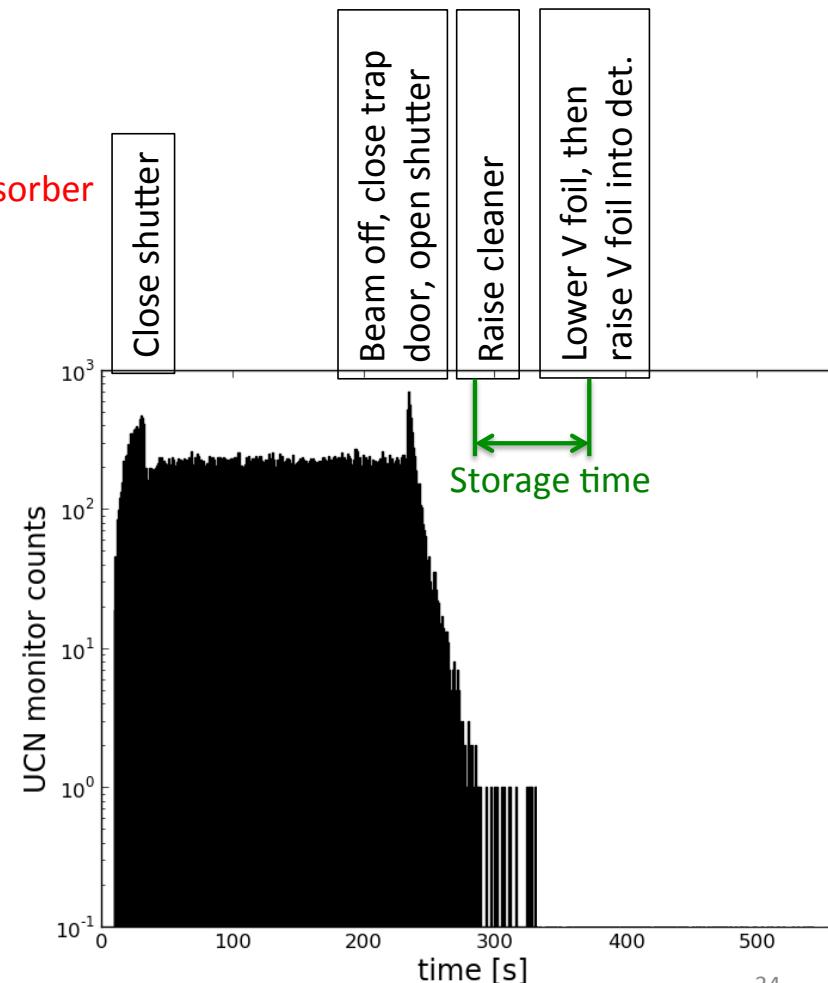
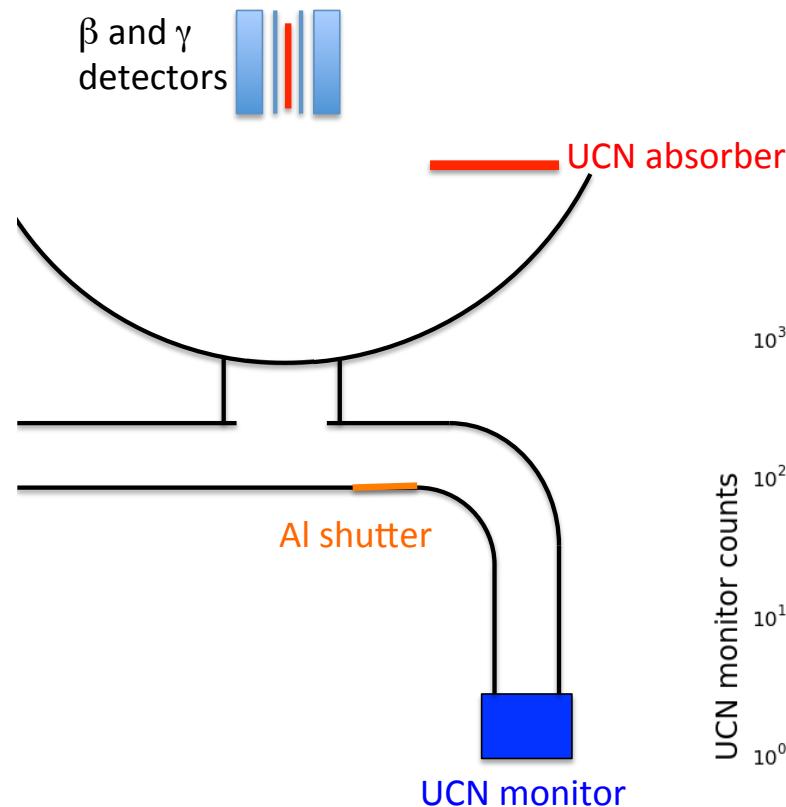
Measurement Cycle

Fill-and-Detect Measurement



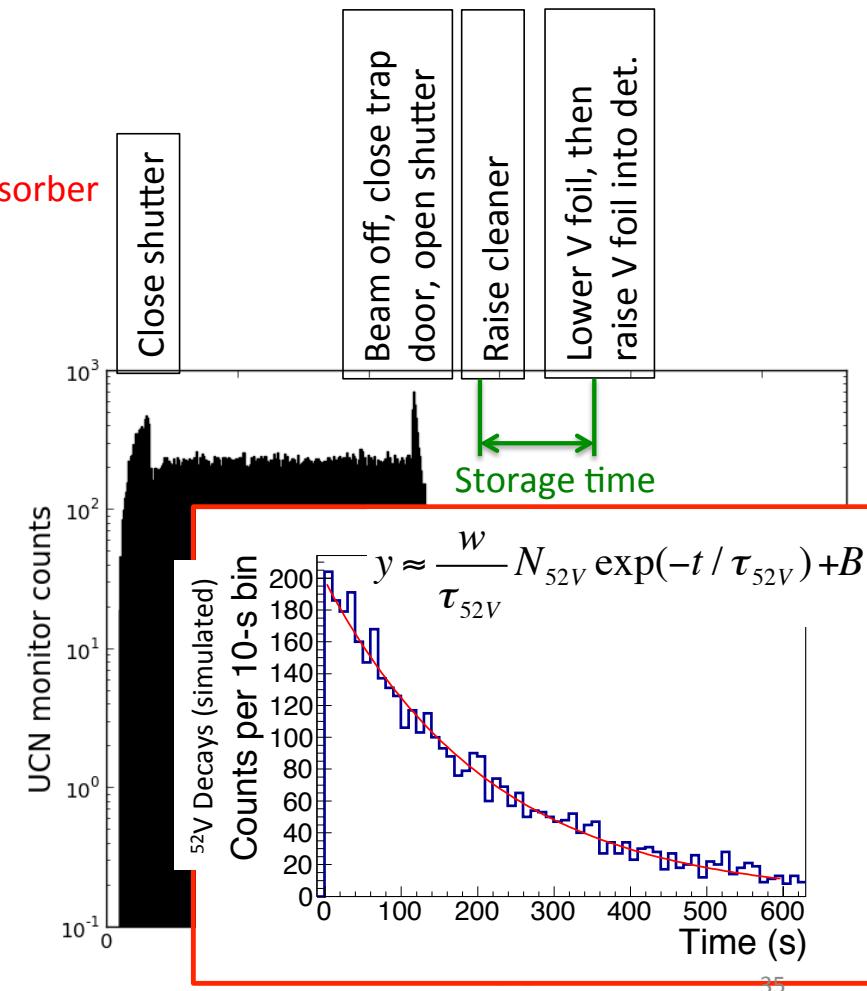
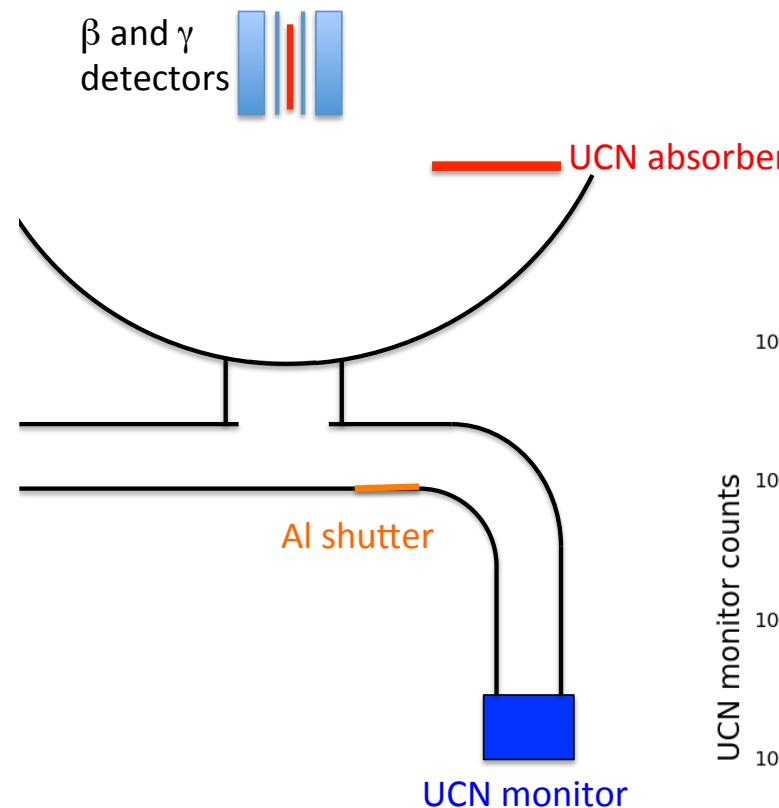
Measurement Cycle

Fill-and-Detect Measurement



Measurement Cycle

Fill-and-Detect Measurement



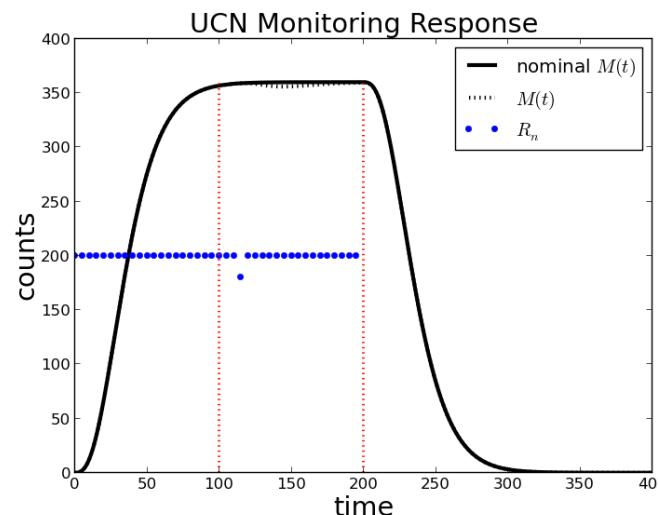
Major Systematic Effects

1 Normalization

- Source Fluctuations
- Insufficient fill time
- Monitor Detector efficiency changes
- Polarization fluctuations
- Variation in trap cleaner height

2 Losses in The Trap

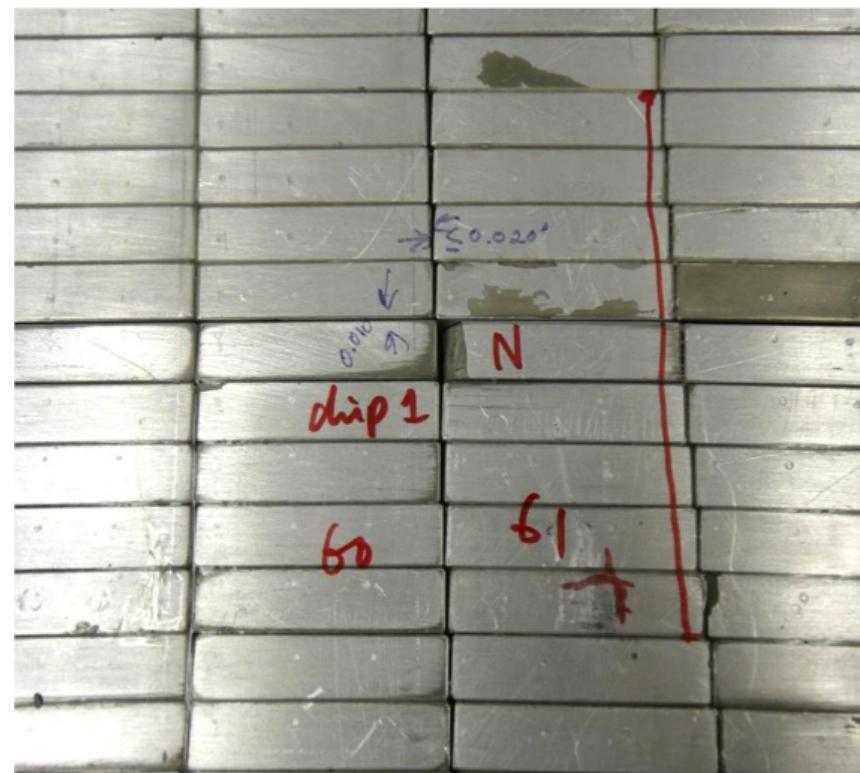
3 Detector Response



Major Systematic Effects

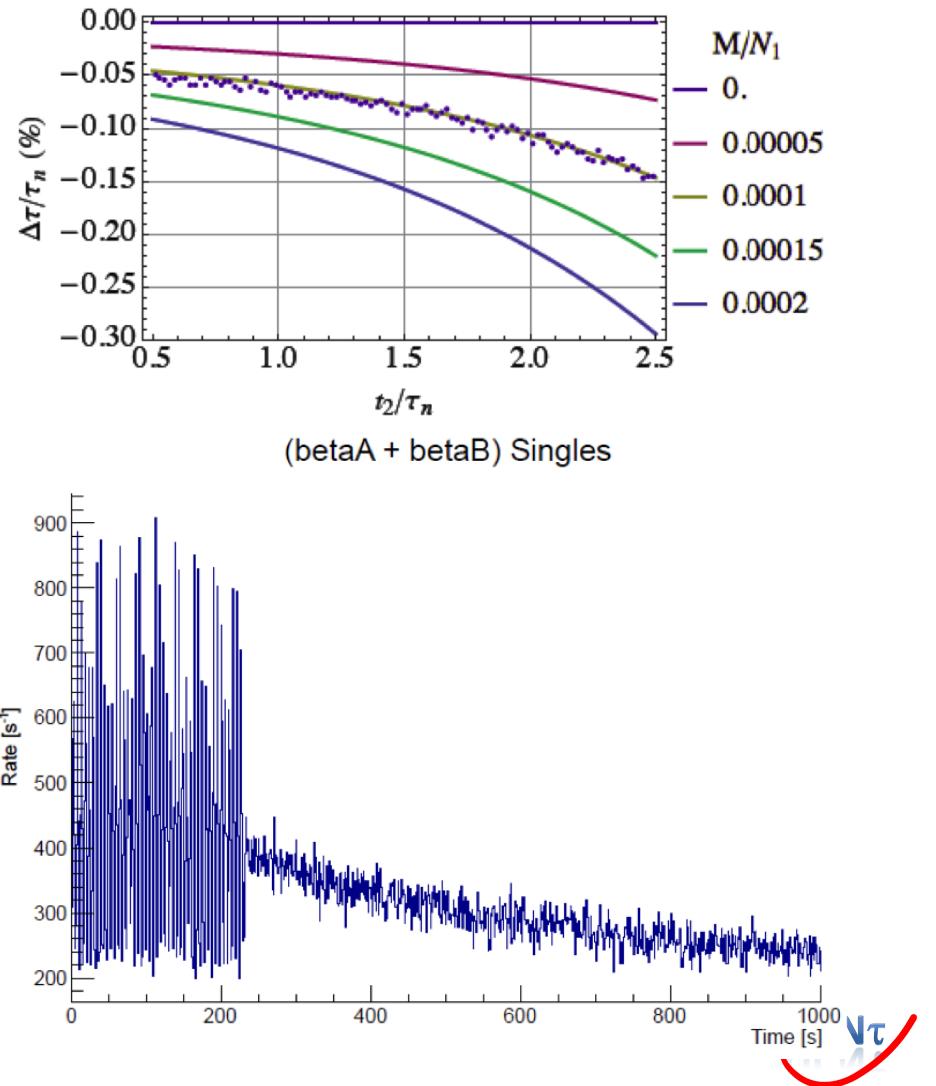
- ① Normalization
- ② Losses in The Trap
 - Residual Gas Scattering
 - Depolarization
 - UCN Heating
 - Leaking through trap door
 - Field holes (trap defects)
 - Material interactions
 - Marginally trapped UCN
- ③ Detector Response

$$\bullet \quad \tau_{trap}^{-1} = \tau_{\beta}^{-1} + \tau_{loss}^{-1}$$



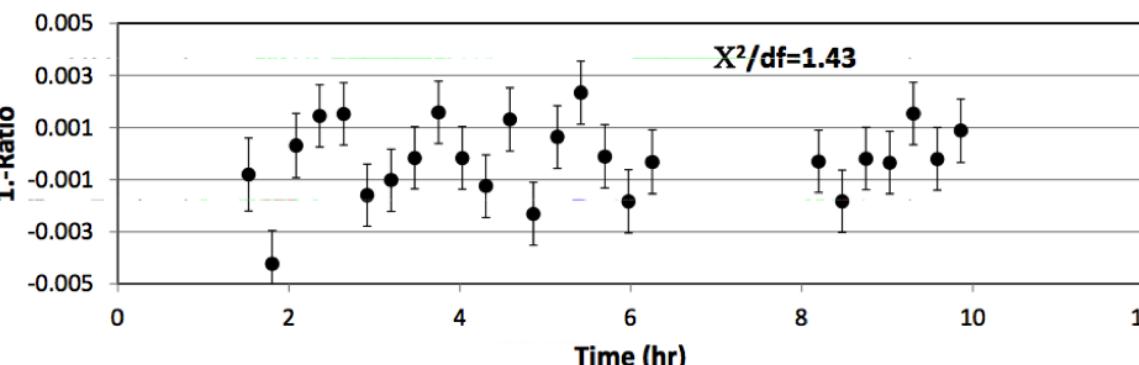
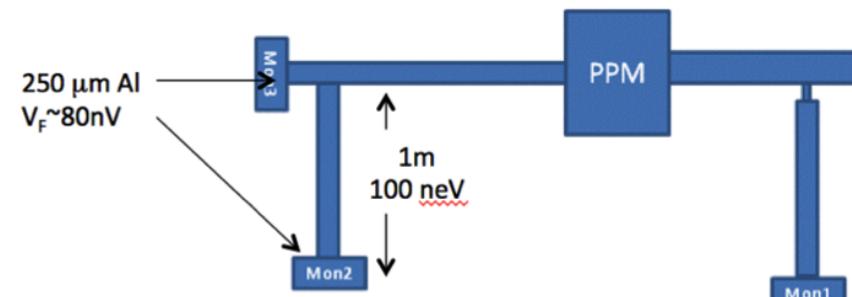
Major Systematic Effects

- ① Normalization
- ② Losses in The Trap
- ③ Detector Response
 - Energy dependent draining
 - Time dependent backgrounds
 - Phase space evolution



Two-point measurement

- $N_1(t_1) = N_{01} e^{-t_1/\tau} + B_1$
- $N_2(t_2) = N_{02} e^{-t_2/\tau} + B_2$
- $\tau = \frac{\Delta t_{1,2}}{\ln\left(\frac{N_1(t_1)-B_1}{N_2(t_2)-B_2}\right) - \ln\left(\frac{N_{01}}{N_{02}}\right)}$
- Ideal case $N_{01} = N_{02}$, trap filled with same number of UCN each run
- Previous tests indicate spectral variations not a problem at 0.1% level

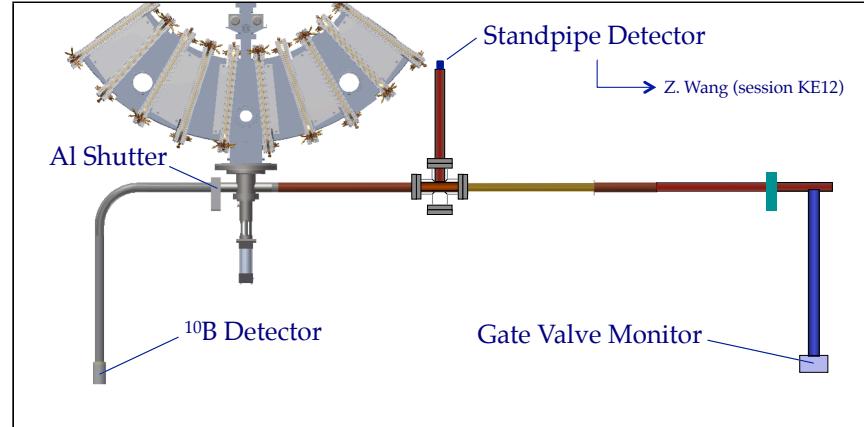


Normalization Variation

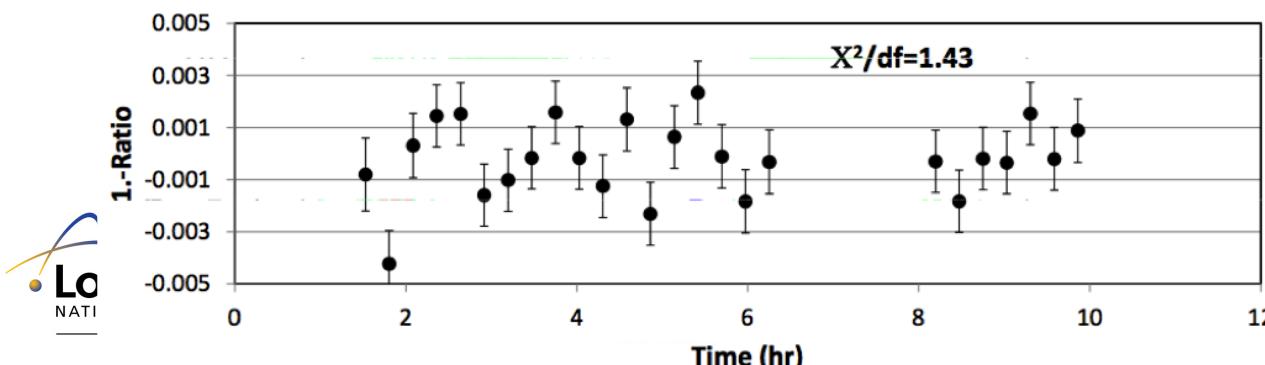
- Proton Current
- Source stability

Two-point measurement

- $N_1(t_1) = N_{01} e^{-t_1/\tau} + B_1$
- $N_2(t_2) = N_{02} e^{-t_2/\tau} + B_2$
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- Ideal case $N_{01} = N_{02}$, trap filled with same number of UCN each run
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- New density monitor detector (see Z. Wang's talk next)

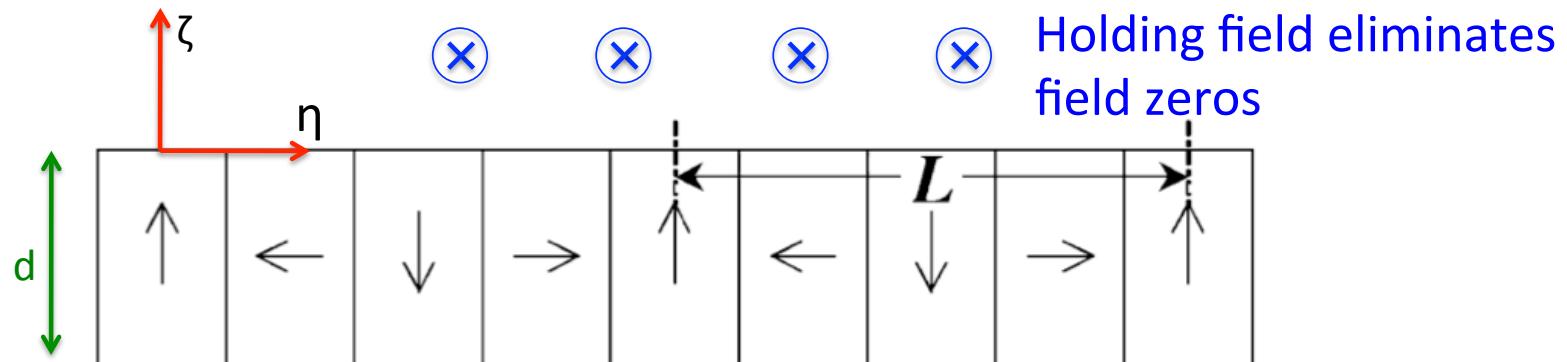


Normalization Variation

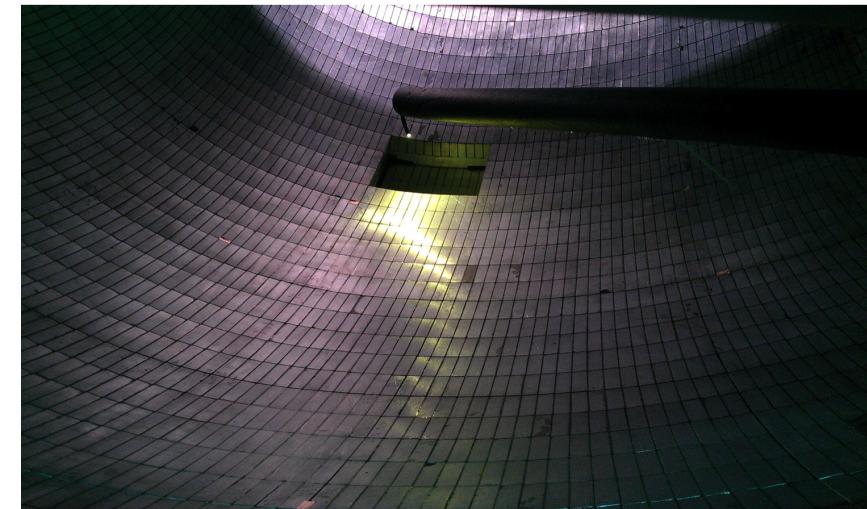
- Proton Current
- Source stability

Halbach Array and Holding Field

$$|\mathbf{B}| = B_{\text{rem}}(1 - e^{-kd})e^{-k\zeta} \quad (\text{if continuous rotation of } M)$$



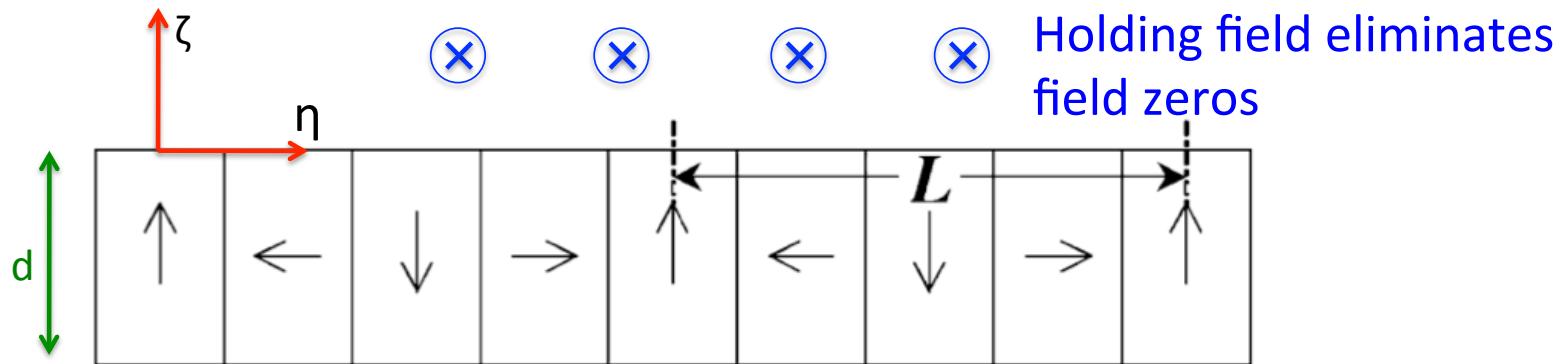
- ① Field zeros induced by reversing holding field coil current
- ② Can study the effect of different holding fields on bottle lifetime



UCN τ
Collaboration

Halbach Array and Holding Field

$$|\mathbf{B}| = B_{\text{rem}}(1 - e^{-kd})e^{-k\zeta} \quad (\text{if continuous rotation of } M)$$

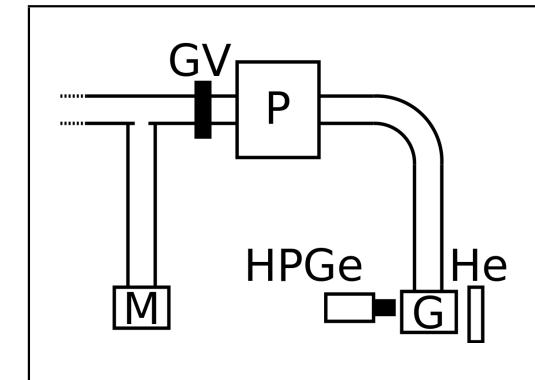


- ① Trap defects are patched with Cu tape ($\sim 42\text{cm}^2$)
- ② τ_n correction of $\sim 0.3\text{s}$
- ③ Depolarization at 50 Gauss 10^{-11} per bounce and a correction of $\sim 10^{-5}\text{s}$ (ideal geometry)



Losses Through Upscattering on Residual Gas

	$\sigma_{\text{scattering}}$ (barns)	$\sigma_{\text{absorption}}$ (NIST)	τ_n/mbar (sec)
Molecule	(660 cm/sec)	(660 cm/sec)	
H ₂	20230 (4000)	222	3
D ₂	3480 (700)	0.35	18
Ne	250 (50)	13	249
Ar	70 (20)	225	891
Xe	190 (40)	7967	328
CF ₄	3320 (660)	14	19
C ₄ H ₁₀	74100 (14800)	1109	1
Air	15730 (3150)	990	4

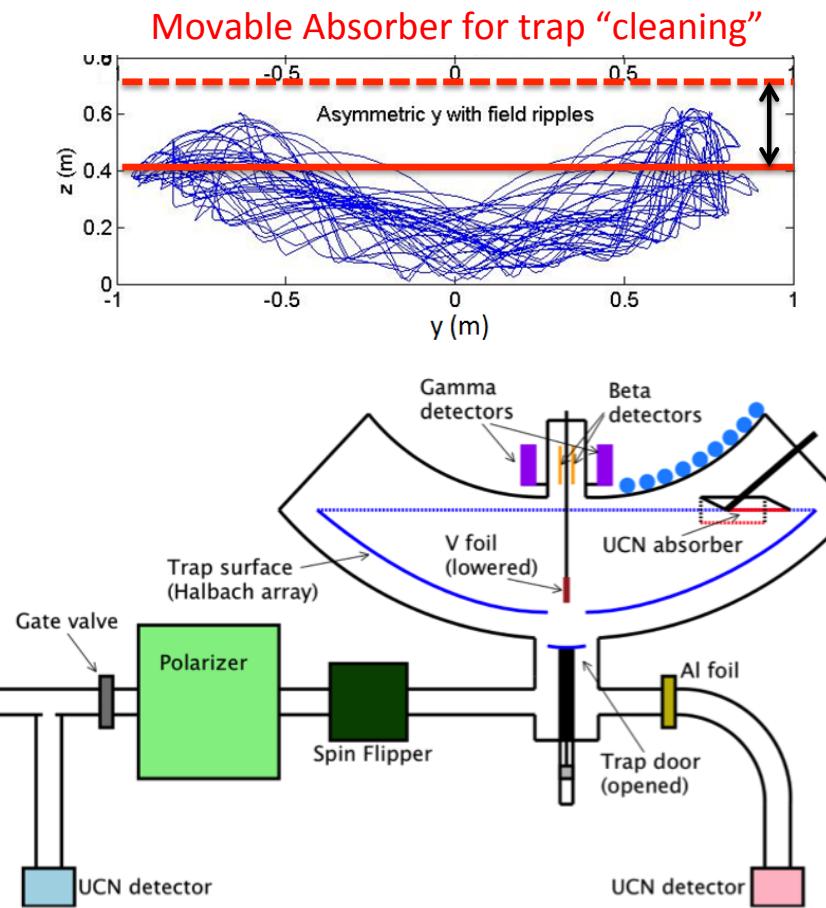


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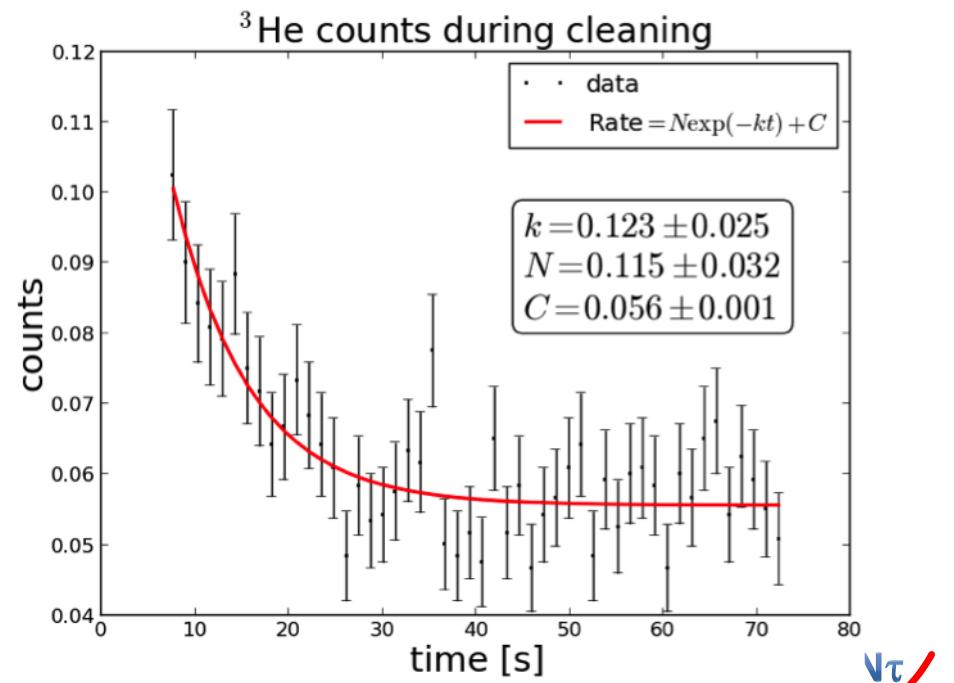
- ① 1.28(26) s correction at 5×10^{-5} mbar (of H₂ and other hydrogenous gases)
- ② 0.26(5) s correction at 1×10^{-5} mbar

- UCN Up-scattering cross sections measured for several gases at LANSCE UCN source
- Installing RGA to monitor gas partial pressures

Cleaning Quasi-bound UCN

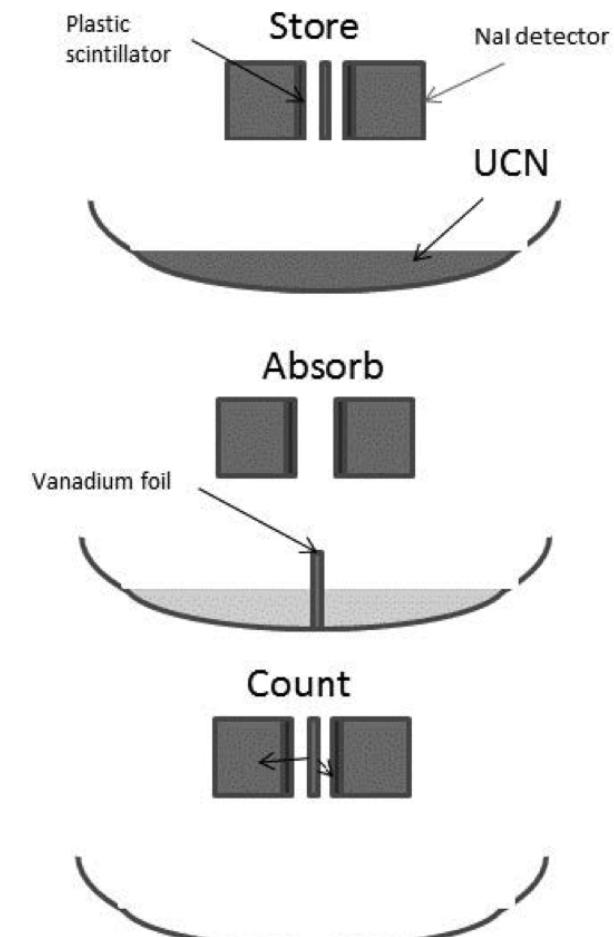
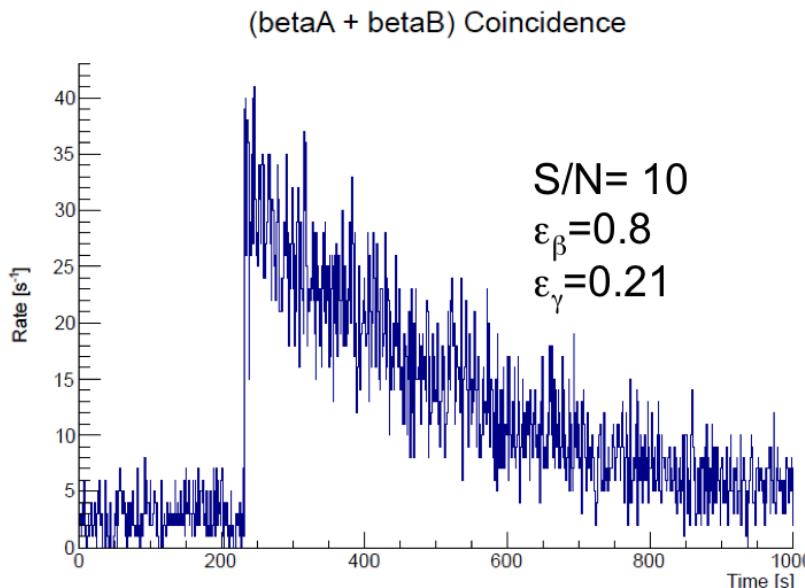


- Proof of principle upscattering measurement with ${}^3\text{He}$
- R&D on active cleaner



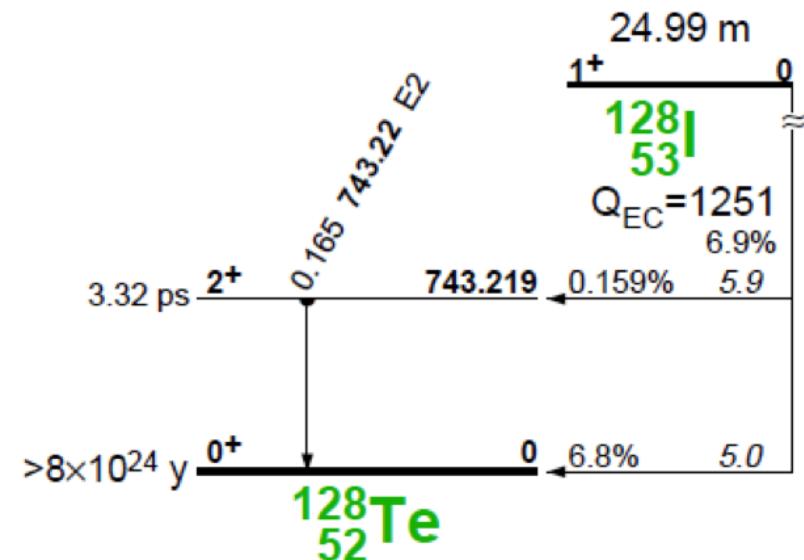
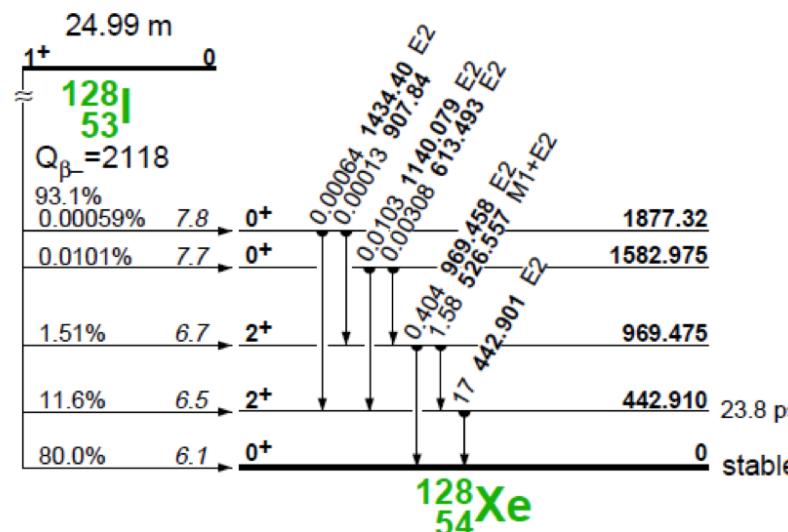
In-situ Counting

- ① Drain time possibly dependent on holding time
- ② $^{51}\text{V} + n \rightarrow ^{52}\text{V}$ ($T_{1/2} = 3.74$ min)
 - $^{52}\text{V} \rightarrow ^{52}\text{Cr} + \beta^- + \gamma$ (1.434 MeV)
- ③ Detect β and γ in coincidence



Iodine Activation in NaI Detectors

- ① Thermal neutrons capture on the Iodine in the NaI detectors
- ② $n + ^{127} I \rightarrow ^{128} I \rightarrow \beta\text{-decay or EC} (\sim 25 \text{ min})$
- ③ Generates time dependent background
- ④ Improved detector shielding to reduce this effect



Conclusion and Summary

- ① 2013 run provided proof of principle for long storage time in trap
- ② Significant improvements made for the 2014/2015 accelerator cycle
 - New trap door/shutter to improve transport into the trap
 - Better shielding around ^{51}V detector system and new β -detector will increase S/N
- ③ Upcoming run cycle will focus on assessing systematics with the goal of a 1 second measurement of the trap lifetime

UCN τ Collaboration

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